EMERSION OF MURRAY CRAYFISH, *EUASTACUS ARMATUS* (DECAPODA:PARASTACIDAE), FROM THE MURRAY RIVER DUE TO POST-FLOOD WATER QUALITY

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Mass emersion of Murray crayfish (*Euastacus armatus*) from the Murray River near Barmah occurred following extensive flooding in Barmah and Millewa Forests in 1992. Crayfish walked out of the river and were observed clinging to the riverbank and partially inundated timber. This behaviour was observed after floodwater, which had been stagnant on the Barmah/Millewa Forest floodplain, had drained from the forest and into the Murray River. At the time of the emersion dissolved oxygen concentrations were below 2.0 mg/L throughout the water column and diel range was from 11–19% saturation.

THE MURRAY, or spiny freshwater crayfish (*Euastacus armatus*) von Martens is present throughout a large proportion of the Murray–Darling Drainage Division incorporating Victorian and southern New South Wales tributaries (Riek 1969) where its geographic range extends over 800 km east–west and 450 km north–south (Morgan 1986). *E. armatus* is now thought to be locally extinct in the Murray River downstream of Mildura (Barker 1990) including South Australia (Zeidler 1982; Geddes et al. 1993) and its distribution in general appears to have declined since European settlement (Barker 1990). The conservation status of *E. armatus* is currently defined as 'Indeterminate' due to '*some populations of the species being at risk from a combination of fishing and other environmental factors*' (Horwitz 1990). Habitat degradation is thought to be the greatest threat to Murray crayfish in Victoria (Barker 1990), however Lintermans & Rutzou (1991) suggest overfishing as the major cause of the decline of Murray crayfish in the ACT. The biology and behaviour of most species of *Euastacus* including *E. armatus* is not well understood (Barker 1990).

Tolerance to various water quality factors have been examined in a number of parastacids (Newcombe 1973; Mills & Geddes 1980; Morrissy et al. 1984) and Unestam (1975) identified the potential for disease to decimate spiny crayfish populations. Although there is limited information available on water quality requirements of Murray crayfish in the species' natural environment (Geddes 1990) they have however been found to be unable to maintain an adequate respiratory rate under hypoxic conditions (Barley 1983; Bezzobs 1988). Geddes et al. (1993) examined the tolerances of Murray crayfish to hypoxia, temperature and salinity.

During flooding, water quality in the Murray River at Barmah is influenced by the changes in water quality which occur in the Barmah/Millewa Forest; a large (60 000 ha), predominantly red gum (*Eucalyptus camaldulensis*), forest (Bren 1988). Due to the narrow channel width of the Murray River between Barmah and Millewa Forests, flooding occurs at relatively low river flows (Dexter et al. 1986). Flooding in the Barmah/Millewa Forest is often widespread and may last for several months, throughout spring and into summer.

Prior to the regulation of the River Murray, Barmah/Millewa Forest was subject to large-scale flooding with much of the floodplain inundated for up to 24 months and 1–9 months on average in winter and spring (Bren 1987). Under current flow regimes, forest flooding is generally less frequent, less extensive and of shorter duration than under natural conditions (Dexter et al. 1986). The flood event which occurred in Barmah/Millewa Forest during 1992 however, could be viewed as having been more typical of a reasonably large scale flood under natural conditions. Flooding peaked in Barmah Forest during the last week in October 1992 in response to high flows in the Murray River downstream of Tocumwal and floodwaters receded from Barmah and Millewa Forests, into the Murray River during November and December.

During the recession of floodwaters into the Murray River from the Barmah and Millewa Forests during December 1992 and January 1993, large numbers of Murray crayfish began walking out of the Murray River between Barmah and the Goulburn River Junction, a distance of approximately 25 km (Fig. 1). The water in the Murray River at this time was extremely dark in colour, a feature attributable to large quantities of dissolved organic matter (Meyer 1990), which impart a yellow-brown colour to the water (Gjessing 1976) giving rise to the term 'blackwater'. Blackwater rivers are present in many parts of the world, particularly tropical areas (Janzen 1974; Meyer 1990) and are typically deficient in oxygen (Janzen 1974). Episodic blackwater events have been observed in temperate mainland Australian rivers on previous occasions (Richardson 1981; Morison 1989) and, in these instances, occurred during the recession of large floods. Murray crayfish have been observed leaving the water during blackwater events following extensive flooding in the Murray River on a number of occasions in previous years (M. Moor, Department of Conservation and Natural Resources, pers. comm.) and in the Goulburn River near Shepparton (B. Simpson, pers. comm.) and in the Murrumbidgee River (B. Jonassen, pers. comm.). Little information is available on the changes in water quality that occur during such events.

Major changes in water quality often occur with floods (Cullen et al. 1978; Beer et al. 1981; Hart et al. 1987, 1988), although many studies have only documented the changes in electrical conductivity, pH, concentrations of suspended solids, ions, trace metals, nutrients and sediment chemistry. There is little published information on changes in dissolved oxygen and concentrations of dissolved organic material associated with flood events in the Murray–Darling Basin. This paper documents a behavioural response in *E. armatus*, describes the nature of the emersion and investigates water quality as an explanation for the behaviour. Water quality is also discussed as a factor possibly affecting the abundance and distribution of *E. armatus*.

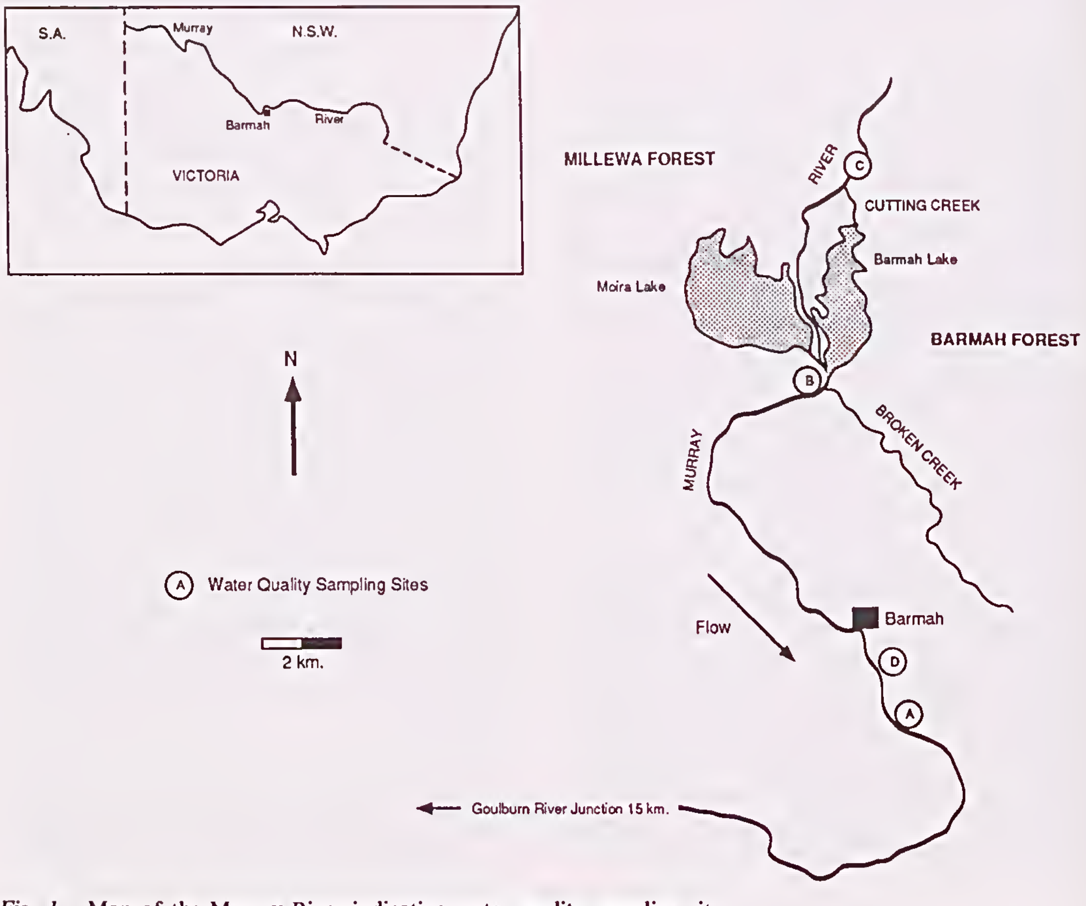

Fig. 1. Map of the Murray River indicating water quality sampling sites.

METHODS

Water quality monitoring sites were chosen to include sites at and upstream of the areas where the emersion of *E. armatus* was observed, and one site where water quality was apparently unaffected by flooding and no crayfish emersion was observed.

On 18 December 1992, water samples were collected downstream of Barmah in the area where the greatest emersion was occurring (site A) and upstream of Barmah where no crayfish emersion was observed (sites B and C) (Fig. 1). Previous fish surveys in the vicinity of sites B and C indicate that Murray crayfish are present at or near these sites (McKinnon, unpubl. data). Water samples for colour and turbidity analysis were collected in 1 L plastic bottles, those for analysis for tannins and lignins collected in 500 mL Pyrex bottles and those for analysis for phenolic compounds in 2.5 L glass Winchester bottles containing 20 mL of 50% w/v sulphuric acid and 2.5 g cupric sulphate (RWC 1988). All water samples were taken at the water surface and immediately stored at 4°C. Water samples were analysed within 48 h at the Rural Water Corporation's State Water Laboratories using standard methods (RWC 1988). In addition, in situ measurements of dissolved oxygen, electrical conductivity, temperature using a TPS 90FL Datalogger, and pH using an Orion 250A model pH meter were made.

On 7 January a TPS 90FL Datalogger was installed in a backwater area on the Murray River (site D, Fig. 1) where crayfish were observed leaving the water in order to monitor the diel changes in dissolved oxygen, temperature, electrical conductivity and pH. Maximum depth at site D was 2.1 m and datalogger probes were fixed at 0.5 m from the bottom. Readings were taken hourly for 5.5 days.

By 21 January 1993, the emersion of crayfish appeared to have ceased and water sampling for colour, turbidity, tannins and lignins and phenols and in situ measurement of dissolved oxygen, temperature, pH and electrical conductivity were repeated at sites A, B and C.

RESULTS

Water quality factors that exhibited the greatest differences between the blackwater sites (sites A and B) and the non-blackwater site (site C) on 18 December, when crayfish were observed leaving the water, were dissolved oxygen and turbidity (Table 1). These were higher at site C and tannins and lignins were slightly lower at this site. Electrical conductivity, pH, colour and phenolic compounds were generally of similar magnitude at all sites.

During the crayfish emersion, water quality factors measured at both blackwater sites (A and B), were of similar magnitude, with the exception of dissolved oxygen (Table 1). Dissolved oxygen at site A, where the emersion was occurring, was 1.8 mg/L, almost half that measured at site B, where no emersion was observed, and one-quarter that measured at site C where neither blackwater nor crayfish emersion was observed (Table 1). Turbidity and pH were lower at sites A and B than at site C and electrical conductivity and levels of tannins and lignins were not significant at sites A and B. At site D dissolved oxygen saturation ranged from just over 19% during the late afternoon to less than 11% in the morning during the

	Crayfish emersion and blackwater observed. Site A (time measured: 1400 h)			Blackwater and no crayfish emersion observed. Site B (time measured: 1510 h)			No crayfish emersion or blackwater observed. Site C (time measured: 1555 h)	
	Mean	s.e.	n	Mean	s.e.	n	Mean	n
Dissolved oxygen (mg/L)	1.8	0	3	3.5	0	2	7.2	1
Temperature (°C)	21.5	0	3	22.0	0	2	22.5	1
pH	6.8	0	3	6.7	0	2	7.5	1
Electrical conductivity (μS/cm)	76.3	0.3	3	82.5	2.5	2	61.0	1
Colour (Pt/Co units)	65.0	0	3	82.5	5.3	2	55.0	1
Turbidity (NTU)	13.0	0.5	3	11.9	5.0	2	43.0	1
Tannins and lignins (mg/L)	1.37	0.03	3	1.55	0.11	2	1.0	1
Phenols (mg/L)	0.006	0.002	3	0.007	0.004	2	0.009	1

Table 1. Water quality factors measured during the period of Murray crayfish emersion, 18/12/1992.

period 8–12 January 1993, while crayfish emersion was still occurring (Fig. 2). During this period pH exhibited apparently normal diel fluctuations but did not reach considerably extreme levels (Fig. 2). Electrical conductivity showed a gradual increase at site D between 8 and 12 January (Fig. 2) as the water level in the Murray River was dropping.

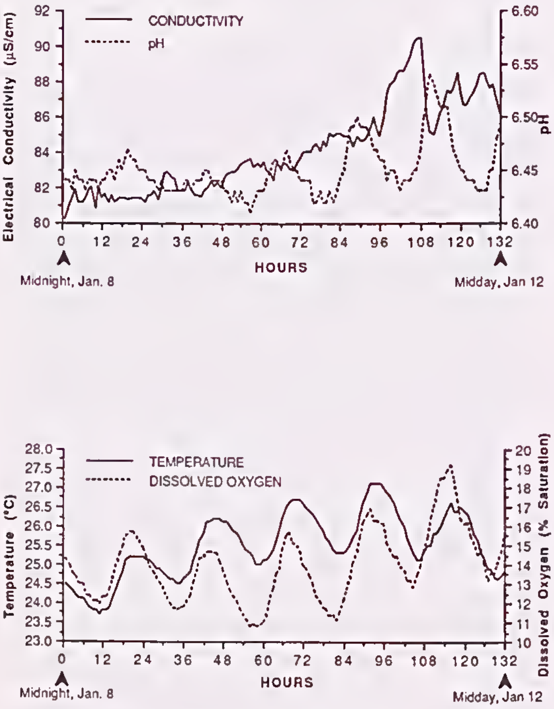

Fig. 2. Diel changes in water quality at site D during the crayfish emersion.

On 21 January dissolved oxygen at sites A and B had increased to levels approximating that recorded at site C and most other water quality factors measured were of similar value at all sites (Table 2). Electrical conductivity, turbidity and concentrations of phenols were higher at site B on 21 January (Table 2) however these could be attributed to the influence of Broken Creek, which receives irrigation drainage water further upstream in the catchment (Fig. 1).

The hydrograph of the Murray River at Barmah from 1 November 1992 to 31 January 1993 (Fig. 3) indicates the period of observed crayfish emersion. The emersion of Murray crayfish began after the floodwaters draining Barmah and Millewa Forests had reached Barmah. This is indicated by a small peak in the hydrograph at Barmah in early December 1992 (Fig. 3). The bulk of the emersion occurred during the first 2–3 weeks of the emersion period and it is expected that the

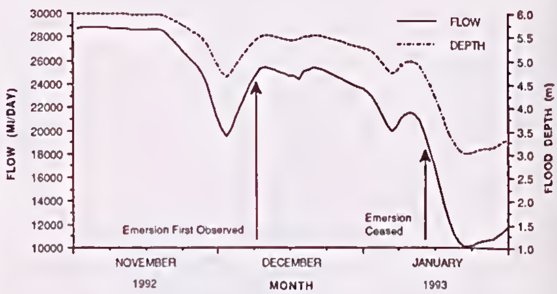

Fig. 3. Hydrograph of the Murray River at Barmah, gauge station 409215, from 1 November 1992 to 31 January 1993.

	Site A (time measured: 1240 h)	Site B (time measured: 1350 h)	Site C (time measured: 1435 h)
Dissolved oxygen (mg/L)	5.6	6.3	6.6
Temperature (°C)	27.8	27.0	27.2
pH	6.9	7.1	7.3
Electrical conductivity (µS/cm)	97.0	112.0	76.0
Colour (Pt/Co units)	65.0	65.0	45.0
Turbidity (NTU)	80.0	83.0	54.0
Tannins and lignins (mg/L)	0.7	0.6	0.4
Phenols (mg/L)	<0.001	0.002	<0.001

Table 2. Water quality factors measured after the period of Murray crayfish emersion, 21/1/1993.

crayfish population in the area suffered significant stock depletion due to removal for domestic consumption. An estimated 500 kg of crayfish was removed during the crayfish emersion period (L. Hubbard, pers. comm.). Emersion continued until mid–late January after which time the forests upstream had ceased to drain and water quality had returned to more favourable levels.

Crayfish were observed walking out of the water and up on to banks along the main river channel and also in backwaters and adjoining billabongs both upstream and downstream of site A from 18 December until late January. The crayfish moved out of the water and remained at the water's edge, semi-exposed keeping their gills at the surface of the water. Some animals were observed walking backwards up partially inundated trees, again keeping their gills at the surface of the water. Individuals returned to the water when disturbed but re-emerged within 0.5 h. Some animals came out of the water completely but would not move further than about 0.25 m from the water's edge. Over a one-hour observation period at site A from 12.30–13.30 hours on 18 October, 30 individuals were observed behaving in this manner in a 400 m. section of riverbank. The smallest and largest individuals observed exhibiting this behaviour were collected and their orbit-carapace length (OCL) measured (25 and 165 mm OCL respectively). The observed behaviour did not appear to be size-specific.

Large schools of Australian smelt (*Retropinna semoni*) and several common carp (*Cyprinus carpio*) were observed swimming at the surface of the water at site A. No dead or obviously moribund fish were observed, however fish kills due to oxygen depletion during the recession of floodwaters have been previously reported (Richardson 1981; McKinnon & Shepheard 1995).

In backwater areas where emersion was occurring, crayfish were generally solitary and behaved independently of one another. Where crayfish were observed clinging to partially inundated trees and woody debris contiguous to fast flowing water, they were often present in groups of three and four, probably due to the scarcity of refuge sites. In these instances, smaller animals were sometimes killed by larger individuals crushing them with their chelipeds. Crayfish were generally lethargic and easy to catch, however only a small number of dead animals was observed. It is assumed that more dead crayfish would have been observed were the moribund animals not removed for human consumption.

DISCUSSION

Much of the floodwater, particularly during the latter stages of the flood, was unable to drain away from the floodplain encompassing Barmah and Moira Lakes (Fig. 1) due to the back-up effect of the Goulburn River which was also in flood, some 45 km downstream. Aerial photography from mid-November indicates the floodwaters at the downstream end of the forests were virtually stagnant at that time. This was depicted by a stream of turbid water flowing down the Murray River, meeting the backed-up floodwater and being deflected westwards into Moira Lake.

As the floodwater remained stagnant, dissolved aquatic humus concentrations would be expected to increase due to the aerobic degradation of organic detritus. This would also be expected to create potentially hypoxic conditions (Welcomme 1979). Dissolved aquatic humus, commonly termed 'tannins and lignins' is further broken down to polyphenolic compounds which are known to be toxic to a wide variety of organisms as they form insoluble complexes with proteins (Janzen 1974). Polyphenolic compounds have been suggested as creating problems with the oxygen exchange surfaces of the gills of fish by binding enzymes on the gills that facilitate respiration (Gehrke 1991; Gehrke et al. 1993). Gehrke et al. (1993) found that this was aggravated in golden perch (*Macquaria ambigua*) larvae exposed to *Eucalyptus camaldulensis* litter leachates under hypoxic conditions. Similar problems may also occur in crayfish exposed to the same conditions. The results from this study indicate that concentrations of tannins and lignins and phenols were similar at sites A, B and C during the period of crayfish emersion. Crayfish emersion was however, only observed at sites A and D at which dissolved oxygen was recorded at concentrations much lower than those recorded at sites B and C.

Geddes et al. (1993) found *E. armatus* held at dissolved oxygen concentrations of 2.1 mg/L for three days did not survive. As dissolved oxygen was recorded at concentrations lower than this for extended periods during the emersion event, it would appear that the effects of hypoxia, possibly combined with the toxic effects of tannins and lignins and phenolic compounds, precipitated the observed behaviour in the crayfish. Studies of the tolerance of a number of *Cherax* species to hypoxia (Barley 1983; Morrissy et al. 1984; Bezzobs 1988) indicate that these species are relatively tolerant of hypoxic conditions. Barley (1983) and Bezzobs (1988) found however, in comparing the tolerance to hypoxia of *C. destructor* with that of *E. armatus*, that both hyperventilated in hypoxic conditions but *E. armatus* was apparently unable to use anaerobic metabolism to replace aerobic respiration as a source of energy. The inability of *E. armatus* to maintain respiration in hypoxic conditions may explain the emersion of this species from the hypoxic floodwaters in the Murray River and may be an important consideration in the general distribution of the species.

The low dissolved oxygen concentrations recorded at site D from 7–13 January and during the initial sampling on 18 December at site A would be expected to have adverse effects on most fish and crustacean species in the area. The conductivity values observed would not be expected to adversely affect crayfish populations (Mills & Geddes 1980; Geddes et al. 1993), nor would the pH values recorded during this time (Newcombe 1973). Specific pH tolerance levels for *E. armatus* however, are not known. It is unlikely that water temperatures recorded would have contributed to crayfish emersion (Geddes et al. 1993).

The relatively poor water quality in the Murray River due to previously stagnating floodwaters draining Barmah and Millewa Forests appeared to have induced the emersion of *E. armatus*. It is clear that the management of flooding or watering strategies for the Barmah and Millewa Forests must take into account the effects on aquatic biota downstream of these forests as floodwaters recede. It is not expected that the response of Murray crayfish observed downstream of Barmah will occur after every flood. It is suggested that the adverse water quality conditions observed on this occasion were the product of floodwaters stagnating due to the backing-up of water in the main channel caused by extensive flooding of tributaries downstream. This allowed dissolved organic matter to collect in the floodwaters and facilitated the production of potentially toxic polyphenols and hypoxic conditions to a greater degree than that which may occur under continuously flowing flood conditions.

The observed effects of stagnating floodwater on water quality is particularly significant when considering the use of earthen block banks and other small scale works as described by Bren (1990) and Murphy (1990) in Barmah and Millewa Forests to retain floodwater. These works have the potential to create extensive areas of stagnant water. Impeding the steady flow of floodwater through the forests by such means may create similar water quality problems to those described in this paper, possibly with similar adverse consequences for the aquatic biota.

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	Crayfish emersion and blackwater observed. Site A (Time measured: 1400h)			Blackwater and no crayfish emersion observed. Site B (Time measured: 1510h)			No crayfish emersion or blackwater observed. Site C (Time measured: 1555h)	
	Mean	s.e.	n	Mean	s.e.	n	Mean	n
Dissolved Oxygen (mg/L)	1.8	0	3	3.5	0	2	7.2	1
Temperature (^{o}C)	21.5	0	3	22.0	0	2	22.5	1
pH	6.8	0	3	6.7	0	2	7.5	1
Electrical Conductivity (µS/cm)	76.3	0.3	3	82.5	2.5	2	61.0	1
Colour (Pt/Co Units)	65.0	0	3	82.5	5.3	2	55.0	1
Turbidity (NTU)	13.0	0.5	3	11.9	5.0	2	43.0	1
Tannins and Lignins (mg/L)	1.37	0.03	3	1.55	0.11	2	1.0	1
Phenols (mg/L)	0.006	0.002	3	0.007	0.004	2	0.009	1

Table 1. Water quality factors measured during the period of Murray crayfish emersion, 18/12/1992.

	Site A (Time measured: 1240h)	Site B (Time measured: 1350h)	Site C (Time measured: 1435h)
Dissolved Oxygen (mg/L)	5.6	6.3	6.6
Temperature (^{o}C)	27.8	27.0	27.2
pH	6.9	7.1	7.3
Electrical Conductivity (µS/cm)	97.0	112.0	76.0
Colour (Pt/Co Units)	65.0	65.0	45.0
Turbidity (NTU)	80.0	83.0	54.0
Tannins and Lignins (mg/L)	0.7	0.6	0.4
Phenols (mg/L)	<0.001	0.002	<0.001

Table 2. Water quality factors measured after the period of Murray crayfish emersion, 21/1/1993.